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of

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for

PRESSURE-COMPENSATED DOWNHOLE BATTERY

RELATED APPLICATIONS

Continuation in Part of Application 10/453,290

BACKGROUND OF THE INVENTION

1. The Field of the Invention

This invention relates to primary and secondary batteries for use downhole for powering a telemetry network and other downhole tools. More specifically, this invention relates to a battery or a fuel cell having internal components that are pressurized to the ambient pressure found downhole, to depths of 20,000 feet or more, in order to compensate for downhole thermal conditions above 120° C.

2. The Relevant Art

At depths of 20,000 feet or more, temperature and pressure may reach levels of 200° C and 10,000 PSI, respectively, providing a hostile environment to downhole drilling components. Moreover, as drilling methods and equipment become more advanced and accurate, newer and more advanced components are continuously being upgraded to perform various functions. Since reliable power may not be readily transmitted to downhole drilling environments, batteries may be used to provide power to various components. Nevertheless, very few batteries are designed to operate in the types of conditions encountered downhole. Moreover, due to space constraints, very few batteries have the desired power densities and dimensions to fit within spaces available in downhole equipment.

For example, few if any batteries are known to operate at temperatures in excess of 170° C. The majority of batteries are designed to function in conditions below 100° C. Thus, very few batteries currently available may be used to provide reliable power sources to downhole drilling components. Thus, apparatus and methods are needed to provide reliable power to downhole components.

The factors affecting downhole pressure are generally the depth of drilling, the hardness and continuity of the subterranean formations being drilled, the composition of the drilling fluid being used, and the under-balanced condition maintained in the well bore.

1 Similar factors are also relevant to the temperature in the well bore. Extreme pressure and
2 thermal conditions in deep wells contribute to premature battery degradation in downhole
3 applications.

4 Generally, downhole batteries are self-contained in their own sealed containers to
5 protect them from ambient conditions, including high pressure and temperature. The need to
6 protect battery components from external pressure may require an expensive pressure
7 housing in the downhole tool. In addition, physical constraints imposed by the geometry of a
8 downhole tool often means that a battery must intrude on the flow space within the tool, or it
9 must be limited to relatively small diameters, reducing overall power density. Moreover,
10 high-pressure housings are always subject to leakage that may lead to a catastrophic failure of
11 a battery and may damage surrounding electronic components as well.

12 U.S. Patent No. 6,187,469, to Marincie et al., incorporated herein by reference, is an
13 example of a downhole battery system. Marincie et al. teaches individual cells mounted end
14 to end and interlocked together to prevent rotation of cells relative to one another. The cells
15 are electrically connected and mounted between an inner and outer tube. The housing for the
16 battery is sufficiently strong to resist downhole pressures and is provided with vents for the
17 discharge of gases.

18 U.S. Patent No. 6,224,997, to Papadopoulos, incorporated herein by reference,
19 teaches a flexible battery pack for powering downhole electronic equipment. The pack
20 includes a plurality of electrochemical cells connected and tied together in a stacked
21 relationship by a pair of semi-cylindrical encapsulating shells which form a primary
22 containment for the cells. The shells comprise a glass fiber reinforced plastic material. The
23 primary containment is sealed within a stainless steel tube that is provided to hold the
24 components in place during operation. Electrical conductors are also provided to transmit
25 energy from the battery to selected downhole equipment. Each cell is sealed to resist the
26 downhole environment and a venting mechanism is provided.

1 U.S. Patent No. 4,087,590, to Kraft, discloses a pressure-equalized electrochemical
2 battery system. Kraft discloses a pack of ordinary, commercially available batteries that are
3 provided with a common electrolyte-filled reservoir coupled to each battery by a small tube.
4 The reservoir includes a compliant diaphragm which, when exposed to pressure, applies the
5 pressure to the reservoir of electrolyte to force it into the battery. Forceful filling of the cells
6 equalizes their internal and external pressures. Kraft is intended for deep-sea applications
7 and would not meet the constraints of a downhole tool string.

8 U.S. Patent No. 6,117,583, to Nilsson, discloses a battery that is intentionally
9 pressurized, but is pressurized above ambient pressure. In lead-acid batteries, PbSO_4 that is
10 formed during discharge has a higher volume than Pb and PbO_2 from which it is formed.
11 When it is discharged, the shrinkage causes a loss of contact between active components and
12 the current conducting lead frame. This is overcome by providing a strong housing that
13 keeps the battery under high pressure.

14 U.S. Patent No. 6,253,847, to Stephensen, discloses a permanent downhole power
15 source for a producing well using a steel casing coated with iron oxide as a cathode. Fe_2O_3 is
16 reduced to FeO . A separate piece of Zinc, as an anode, is provided which corrodes and is
17 consumed. A cement treated with additives, to increase its conductivity, serves as an
18 electrolyte.

19 In view of the foregoing, what is needed is a long life battery that will accommodate
20 the temperature, pressure, and physical constraints of downhole tools and be functional to
21 depths of 20,000 feet or more.

SUMMARY OF THE INVENTION

In view of the foregoing, it is a primary object of the present invention to provide a robust battery for supplying power to various downhole components, such as to downhole networking components, in the presence of hostile downhole conditions, such as high temperature, pressure, dirt, rocks, mud, fluids, lubricants, and the like. It is a further object of the invention to increase the thermal range of a battery's operation by transferring pressure encountered downhole to components within the battery.

Consistent with the foregoing objects, and in accordance with the invention as embodied and broadly described herein, in one embodiment in accordance with the invention, a pressure-balanced battery for powering downhole drilling components in a subterranean environment includes a battery and a housing enclosing and sealing a volume containing the battery. The housing may be expandable and contractible to balance pressure internal to the housing with pressure external to the housing.

In selected embodiments, the housing is in operable communication with downhole fluids to transfer pressure to the battery. In other embodiments, the housing is integrated into the annular structure of a downhole tool. In certain embodiments, a portion of the housing is machined, milled, cast, and forged into the structure of a downhole tool.

The battery may include one or several cells electrically connected in series, parallel, or a combination thereof, within the housing. The battery cells may be held together by a flexible casing having a substantially planar or flat shape, a cylindrical shape, a semi-cylindrical shape, or any other shape, as needed, to fit within the particular constraints imposed by the downhole tool.

One or several battery terminals may be connected to the battery and be accessible through an opening in the housing. The battery may include an electrolyte that is a fluid electrolyte, a solid electrolyte, or a combination thereof. In selected embodiments, the battery is a fuel cell. In selected embodiments, the battery may be installed into one or several recesses formed in the wall of a downhole tool.

1 The battery may be used to supply power to components of a downhole network,
2 other downhole tools, transmission elements configured to transmit information between
3 downhole tools, and the like. In selected embodiments, a signal-conditioning module may be
4 provided with the battery to modify characteristics of power output from the battery. The
5 battery may be a single-use battery or rechargeable.

6 In another aspect of the present invention, a pressure-balanced battery for powering
7 downhole-drilling components in a subterranean environment includes a battery and a
8 housing enclosing and sealing a volume containing the battery. The housing may include a
9 substantially rigid portion and a resilient portion deformable to vary the volume of the
10 housing. The resilient portion may balance pressure internal to the housing with ambient
11 pressure external to the housing.

12 In selected embodiments, the resilient portion of the housing is in operable
13 communication with downhole fluids. The housing may be integrated into the annular
14 structure of a downhole tool. The rigid portion of the housing may be machined, milled,
15 cast, forged, and the like, into the structure of a downhole tool.

16 In selected embodiments, the battery includes one or several cells electrically
17 connected in series, parallel, or a combination thereof, within the housing. The battery may
18 also include one or several battery terminals, operably connected to the battery, accessible
19 through an opening in the housing.

20 In another aspect of the present invention, a method for providing power to
21 downhole drilling components in a subterranean environment may include providing a
22 battery, providing a sealed housing for the battery having a resilient portion flexible to vary
23 the volume within the housing, and flexing the resilient portion to balance pressure internal
24 to the housing with pressure external to the housing. In selected embodiments, the flexing of
25 the resilient portion may be actuated by communication between downhole fluids and the
26 resilient portion of the housing.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features of the present invention will become more fully apparent from the following description, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only typical embodiments in accordance with the invention and are, therefore, not to be considered limiting of its scope, the invention will be described with additional specificity and detail through use of the accompanying drawings in which:

Figure 1 is a perspective view illustrating one embodiment of a downhole tool, such as a section of drill pipe;

Figure 2 is a perspective cross-sectional view of interior characteristics of one embodiment of a downhole tool as illustrated in Figure 1;

Figure 3 is an exploded perspective view of one embodiment of a battery cell in accordance with the invention;

Figure 4 is a perspective view illustrating one embodiment of a battery comprising multiple battery cells integrated into a cylindrical casing for integration into a downhole tool;

Figure 5 is a perspective view illustrating another embodiment of a battery in accordance with the invention, having a semi-cylindrical shape;

Figure 6 is a perspective view illustrating one embodiment of a planar or flat implementation of a battery in accordance with the invention, having one or multiple layers;

Figure 7 is a perspective cross-sectional view illustrating one embodiment of a battery, having a cylindrical configuration, installed into a downhole tool;

Figure 8 is a perspective cross-sectional view illustrating one embodiment of a battery having a semi-cylindrical shape installed into the annular structure of a downhole tool; and

Figure 9 is a perspective view illustrating one embodiment of a battery insert that may be installed or inserted into another downhole tool.

DETAILED DESCRIPTION OF THE INVENTION

It will be readily understood that the components of the present invention, as generally described and illustrated in the Figures herein, could be arranged and designed in a wide variety of different configurations. Thus, the following more detailed description of embodiments of apparatus and methods of the present invention, as represented in the Figures, is not intended to limit the scope of the invention, as claimed, but is merely representative of various selected embodiments of the invention.

The illustrated embodiments of the invention will be best understood by reference to the drawings, wherein like parts are designated by like numerals throughout. Those of ordinary skill in the art will, of course, appreciate that various modifications to the apparatus and methods described herein may easily be made without departing from the essential characteristics of the invention, as described in connection with the Figures. Thus, the following description of the Figures is intended only by way of example, and simply illustrates certain selected embodiments consistent with the invention as claimed herein.

Referring to Figure 1, a downhole tool 10 may generally be constrained to have a design or configuration similar to that illustrated. Thus, any desired functions, tools, sensors, or other features generally requires the design of such to operate within the dimensions and other constraints imposed by the downhole environment. In general, a downhole tool 10 may include a tubular tool body 11 having a pin end 12 and box end 13, providing tool joints 12, 13 for connecting to other downhole tools 10, such as other sections of drill pipe 10. Due to additional stresses imposed thereon, tool joints 12, 13 may include additional wall thickness or structure to reliably support the added stress. The pin end 12 and box end 13 may include an external and internal threaded portion, respectively, to thread into corresponding threaded portions of other similar downhole tools 10.

Referring to Figure 2, internally, a downhole tool 10 may include a central bore 19 running the length thereof. The central bore 19 may taper off at transition areas 18 to smaller

1 diameter bores 16 passing through the tool joints 12, 13. The smaller diameter bores 16 may
2 be provided to add structural support near the tool joints 12, 13.

3 The size of the central bore 19 and smaller bores 16 may be such as to enable mud or
4 other drilling fluids to pass through the bores 16, 19 with a minimum level of restriction. In
5 addition, the bores 16, 19 may generally require a certain diameter in order to lower tools or
6 other components through the central bore down the drill string. Thus, batteries intended for
7 function downhole generally are constrained to reside within the annular walls of a downhole
8 tool 10 without overly compromising the strength of a downhole tool 10 and without
9 restricting diameter requirements of the bores 16, 19.

10 As was previously mentioned, few if any batteries are designed to function within
11 the constraints imposed by downhole tools 10 in a subterranean environment. Moreover, few
12 if any batteries are designed to function in the hostile environment downhole characterized
13 by temperatures of 200° C or more, and pressures nearing or exceeding 10,000 PSI.
14 Conditions that prevent batteries from functioning at such high pressures and temperatures
15 may be understood by effects that occur under these conditions.

16 Most batteries function by creating electrical power from chemical reactions
17 occurring within the battery. Substances and materials such as electrolytes and dielectric
18 materials, whether they are in a solid or liquid form, are integral to the chemical reaction
19 within a battery. At high temperatures, these materials may begin to boil, vaporize, outgas,
20 or the like, thereby weakening or destroying operation of the battery.

21 Thus, if batteries are to survive and function in downhole environments, apparatus
22 and methods are needed to prevent, reduce, or minimize the effects of boiling, vaporization,
23 or outgassing of materials within a selected battery. Moreover, the battery should also have
24 suitable dimensions and flexibility to function within the space constraints required by
25 downhole tools 10.

26 In general, the temperature at which a liquid or solid boils, vaporizes, or outgases is
27 directly related to the pressure of the surrounding environment. Thus, if pressure is

1 increased, boiling or rates of outgassing may be shifted to occur at higher temperatures. If
2 pressures encountered in downhole environments are applied to materials such as electrolytes
3 or dielectrics found within selected batteries, boiling or outgassing that might otherwise
4 result may be reduced or eliminated. Thus, batteries not designed to function in
5 environments of high temperature and pressure, such as those experienced downhole, may be
6 made to function in environments having temperatures nearing or exceeding 200° C and
7 pressures reaching or exceeding 10,000 PSI.

8 Referring to Figure 3, in one embodiment, a battery cell 20 in accordance with the
9 invention, may be designed to be relatively flat and flexible to fit within the constraints
10 imposed by a downhole tool 10. Thus, a battery cell 20, as illustrated, may take on a
11 relatively flat, rounded, or curved shape, as desired. In addition, selected batteries having
12 higher power densities per volume may be more preferable for use in the present invention
13 due to the space constraints. Nevertheless, any of the various known types of batteries, such
14 as lithium-ion, nickel-cadmium, nickel-metal hydride, zinc-carbon, alkaline, silver-zinc, and
15 the like, to name a few, or various types of fuel cells, are certainly within the scope of the
16 present invention.

17 In one embodiment, a battery cell 20 such as a lithium-ion battery 20, may include a
18 flexible casing 21a, 21b enclosing internal components of the battery cell 20. The battery cell
19 20 may include a positive copper foil 22 coated with an anode material to serve as a current
20 collector, which may or may not be enclosed in an anode housing 23. In addition, the battery
21 cell 20 may include various dielectric separators 24, 27, and an electrolyte layer 25 which
22 may or may not be enclosed or protected by a housing 26. The battery cell 20 may also
23 include a negative copper metal foil 29 coated with a cathode material to function as a
24 negative current collector, which may or may not be enclosed in a housing 28. The battery
25 cell 20 may also include a pair of positive and negative terminals 30, 31, or printed traces 30,
26 31, to supply power to other components from the battery cell 20. The battery cell 20 may be
27

1 designed to function as a primary or secondary battery, meaning that the battery cell 20 may
2 be a single-use battery, or may be rechargeable for multiple uses.

3 Other electrochemical power storage and generating systems may accommodate the
4 constraints of a downhole system and be suitable for downhole use by exposing them to
5 downhole pressure and temperature. All or part of such systems include liquid and solid
6 state electrolyte systems as disclosed in U.S. Patent No. 6,506,511, to Lakeman, and U.S.
7 Patent No. 6,528,204, to Hikmet, both of which are incorporated herein by reference. The
8 electrochemical systems disclosed in these references are configured to be includible within
9 the physical constraints of various downhole tools. Additionally, they demonstrate the
10 breadth of electrolytic components that might benefit from being exposed to a downhole
11 environment rather than being protected from it.

12 Referring to Figure 4, in selected embodiments, battery cells 20, as illustrated in
13 Figure 3, may be combined into a matrix or array of battery cells 20 in order to provide
14 desired voltage and power. For example, a battery 32 including multiple battery cells 20,
15 may be combined into a matrix or array of battery cells 20 within a cylindrical casing 33.
16 The cylindrical casing 33 may be constructed of any suitable material.

17 In selected embodiments, battery cells 20 may be encapsulated or sandwiched within
18 the material of the cylindrical casing 33, or may be attached by any suitable means onto the
19 exterior or interior surface thereof. In selected embodiments, the cylindrical casing 33 may
20 be constructed of a material such as that used to construct various circuit boards. In this
21 embodiment, metal traces (not shown) may be etched or otherwise attached to the cylindrical
22 casing 33 to connect the battery cells 20 in series, parallel, or a combination thereof, in order
23 to provide desired voltage and power characteristics to the battery 32.

24 In selected embodiments, the battery 32 may include a gap 34. The gap 34 may
25 enable expansion or contraction of the diameter of the cylindrical casing 33 in order to insert
26 the battery 32 into a downhole tool 10. Once the battery 32 is inserted into the downhole tool
27 10, the diameter of the cylindrical casing 33 may expand to fit snugly to the inside diameter

1 of the downhole tool 10. The length of the cylindrical casing 33 may be adjusted as needed
2 to provide more or less battery cells 20 to the battery 32.

3 Referring to Figure 5, in a similar manner, a battery 32 may be designed to have any
4 desired shape or configuration. For example, in selected embodiments, a battery 32 may be
5 configured to have a rounded or semi-cylindrical shape. This shape may enable insertion or
6 housing of the battery 32 within recesses formed in the annular walls of downhole tools 10.
7 As was stated previously, the dimensions of the cylindrical or semi-cylindrical casing 33 may
8 be varied as needed to fit within the particular constraints of a downhole tool 10, or to
9 accommodate additional battery cells 20 to provide desired power or voltage.

10 Referring to Figure 6, likewise, a battery 32 may include one or several layer 35a-c in
11 a substantially planar or flat configuration. Providing cells 20 in layers 35a-c may enable
12 stacking of the layers 35a-c to provide desired dimensions, thickness, and power density to
13 the battery 32 in order to fit within space constraints of a downhole tool 10. In reality, the
14 different configurations of batteries 32 illustrated in Figures 4-6 simply represent certain
15 contemplated shapes of batteries 32 in accordance with the present invention. Many other
16 shapes are possible and may be desirable depending on the design constraints. All of these
17 are intended to be captured within the scope of the present invention.

18 Referring to Figure 7, while continuing to refer generally to Figure 4, a battery 32
19 having a cylindrical configuration may be housed within a downhole tool 10. The downhole
20 tool 10 may be a tool 10 specifically dedicated as a battery, or may be a tool 10 having other
21 functions or purposes that has a battery 32 integrated therein. A cylindrical battery 32 may
22 be inserted or installed into the downhole tool 10 to sit against the inside wall or inside
23 diameter of the tubular body 15.

24 In selected embodiments, a recess may be milled or formed on the inside wall of the
25 tubular body 15 to accommodate the battery 32. A flexible or compliant liner 36, made of
26 stainless steel, plastic, or some other suitable material capable of withstanding the rigors of a
27 downhole environment, may be inserted into the inside diameter of the downhole tool 10

1 such as to sandwich the cylindrical battery 32 between the liner 36 and structure of the
2 tubular body 15.

3 The liner 36 may be sufficiently flexible or compliant to transfer pressure within the
4 inside diameter of the liner 36 to the battery 32. That is, the pressure of mud, air, or other
5 drilling fluids traveling through the liner 36 may cause the diameter of the liner 36 to expand,
6 thereby increasing pressure on the battery 32. By transferring pressure to the battery 32, the
7 thermal operating range of the battery 32 may be increased by increasing the boiling point,
8 vaporization, or outgassing temperature of dielectric materials, electrolytes, or other
9 materials within the battery 32. Thus, a battery 32 which might not normally be operable at
10 such pressures and temperatures, may function in a downhole environment.

11 In selected embodiments, one or multiple leads 38a, 38b may extend from the battery
12 32. In selected embodiments, the leads 38a, 38b may feed power to a signal-conditioning
13 module 40. The signal-conditioning module 40 may condition or process voltage and current
14 output from the battery 32 to provide desired power characteristics. For example, in selected
15 embodiments, the signal-conditioning module 40 may provide consistent power,
16 uninterrupted power, prevent undesired power surges, and the like. In selected embodiments,
17 the signal conditioning-module 40 may include various recesses 41 or compartments 41
18 housing various electronic components to provide the functionality of the signal-conditioning
19 module 40.

20 In selected embodiments, power from the battery 32 may be transferred to other
21 downhole tools 10 by way of transmission elements 42a, 42b, located on primary or
22 secondary shoulders of the pin end 12 or box end 13 of a downhole tool 10. In selected
23 embodiments, power may be transmitted by direct electrical contact with corresponding
24 transmission elements located on other downhole tools 10 connected in series along a drill
25 string. In other embodiments, electrical power received from the battery 32 may be
26 converted by induction to magnetic energy to bridge the gap between downhole tools 10.
27 The magnetic energy may then be detected and converted back to an electrical signal.

1 Referring to Figure 8, in selected embodiments, a semi-cylindrical battery 32 such as
2 that illustrated in Figure 5, may be installed into the outer wall 11 of a downhole tool 10. For
3 example, recesses may be formed or milled into the outside or inside diameter of a downhole
4 tool 10 to house the battery 32. One or several batteries 32 may be inserted into these
5 recesses and may be covered by a cover plate 44 or other suitable protective covering 44.
6 The recesses may be formed or milled into the downhole tool 10, such as to not overly
7 weaken or compromise the strength of the downhole tool 10.

8 Although not illustrated, other recesses may be provided in the wall of the tool 10 to
9 house signal conditioning or other equipment to provide desired power characteristics. The
10 cover plate 44 or material 44 may be sufficiently resilient to withstand the hostile
11 environment downhole, while still enabling pressure from the downhole environment to be
12 transmitted to the battery 32.

13 Referring to Figure 9, in selected embodiments, a tool insert 45 containing one or
14 several batteries 32 may be provided for insertion into another downhole tool 10. The insert
15 45 may include an inside diameter sufficiently large to not overly impede or restrict the flow
16 of mud or other drilling fluids passing therethrough. The insert 45 may include various
17 surfaces 46, 50 of differing diameters to fit and be retained within another downhole tool 10.

18 In selected embodiments, the insert 45 may include one or several recesses 47 milled
19 into the annular walls of the insert 45. These recesses 47 may house or contain batteries 32
20 in accordance with the present invention, such as those illustrated in Figure 6, for example.
21 In selected embodiments, the recesses 47 may include one or several apertures 48 opening
22 into the inside diameter 49 of the insert 45. These apertures 48 may provide communication
23 with mud or other drilling fluids traveling through the inside diameter 49, thereby enabling
24 the transfer of pressure to batteries 32 contained within the recess 47 or recesses 47.

25 In selected embodiments, a diaphragm, membrane, or other resilient and flexible
26 material may be inserted into the apertures 48 in order to seal and protect batteries 32
27 contained in the recesses 47 from contamination from mud or other drilling fluids circulated

1 through the bore 49. Thus, batteries 32 contained in the recesses 47 may be pressurized
2 using pressures experienced downhole to increase the thermal range of the batteries 32.

3 The present invention may be embodied in other specific forms without departing
4 from its essence or essential characteristics. The described embodiments are to be
5 considered in all respects only as illustrative, and not restrictive. The scope of the invention
6 is, therefore, indicated by the appended claims, rather than by the foregoing description. All
7 changes within the meaning and range of equivalency of the claims are to be embraced
8 within their scope.

9 What is claimed and desired to be secured by United States Letters Patent is:
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